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# PATENT SPECIFICATION

DRAWINGS ATTACHED

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## COMPLETE SPECIFICATION

### Staple Metal Fibers and Porous Metal Web Structures Formed from such Fibers

We, BRUNSWICK CORPORATION, a corporation organized and existing under the laws of the State of Delaware, United States of America, of 69 West Washington Street, Chicago, Illinois, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to porous metal structures comprised of interlocked metal fibers, and to the fibers used to form such structures.

The metal fiber structures of the present invention are entirely different from conventional steel wools and the like, where fibers are produced by urging cutting tools against a metal surface to scrape off a thin sliver of metal. The width of such slivers is many times their thickness, for example ten times, whereas the fibers used in the structures of the present invention are preferably of generally circular cross section, that is the transverse dimension of any given fiber is substantially the same whatever the direction in which it is measured. Moreover, the production of metal fibers by scraping causes numerous fractures to occur in the metal, whereas the fibres used in the structures of the present invention are substantially free of such fractures.

In accordance with the invention a porous metal web structure comprises a plurality of substantially fracture-free, unmachined and unburnished metal staple fibers each of which has in any selected cross-section a mean transverse dimension, of effective diameter, of less than 50 microns, said fibers having rough outer surfaces and being interlocked in an intermingled relationship substantially solely

by means of said rough outer surfaces thereof in frictional engagement.

The invention also includes the new staple metal fiber as such. Further features of the invention will sufficiently appear from the appended claims when read in the light of the following description, given with reference to the accompanying drawings, of particular ways of practising the invention. In the drawings:

Figure 1 is a fragmentary section of a porous metal structure embodying the invention;

Figure 2 is a fragmentary side elevation of a metal fiber for use therein;

Figure 3 is an end elevation of the fiber of Figure 2;

Figure 4 is a transverse section thereof taken substantially along the line 4—4 of Figure 2;

Figure 5 is a broken side elevation of another form of metal fiber for use in the porous metal structure;

Figure 6 is an end elevation of the fiber of Figure 5;

Figure 7 is a schematic illustration of one step in a method of forming the metal fibers;

Figure 8 is a transverse section taken substantially along the line 8—8 of Figure 7;

Figure 9 is a schematic representation of another step in the forming of the metal fibers;

Figure 10 is a side elevation of a tow of metal filaments formed as by the steps of Figures 7 through 9;

Figure 11 is a schematic side elevation of an apparatus for breaking the filaments illustrated in Figure 10 into fiber lengths;

Figure 12 is a side elevation of a tow of the filaments broken into such fiber lengths;

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Figure 13 is a schematic block diagram illustrating one method of forming a porous metal structure from the fibers of Figure 12;

5 Figure 14 is a schematic block diagram illustrating another method of forming a porous metal structure from the fibers of Figure 12;

10 Figure 15 is a schematic block diagram of still another method of forming a porous metal structure from the fibers of Figure 12;

15 Figure 16 is a side elevation of a porous metal structure formed of metal fibers having different diameters;

Figure 17 is a side elevation of a porous metal structure having fibers of different diameters generally arranged in different layers;

20 Figure 18 is an enlarged elevation of a porous metal structure illustrating the contacting of the fibers one with the other at essentially point contacts;

25 Figure 19 is a side elevation of a porous metal structure wherein the fibers are arranged in a plurality of layers wherein the fibers of the different layers vary in size;

Figure 20 is a side elevation of a creped porous metal structure embodying the invention; and

30 Figure 21 is a side elevation of an uncompacted porous metal structure embodying the invention.

35 In the exemplary embodiment of the invention as disclosed in Figure 1 of the drawing, a porous metal structure generally designated 10 is shown to comprise a plurality of webs 11, 12 and 13 of metal fibers 14. The metal fibers 14 are essentially fracture free, each having a cross-section which although irregular is generally circular, that is radially substantially symmetrical, with a mean transverse dimension, or effective diameter, of less than 50 microns. The metal fibers 14 are interlocked in an intermingled relationship in the structure 10 substantially solely by means of the rough outer surfaces thereof in frictional engagement, though there may be a small amount of positive interlocking between the fibers as a result of curl imparted to them during manufacture, as explained below. The structure 10 is a nonwoven web material which does not depend either upon interweaving of the individual fibers, or the use of bonding material to maintain the integrity thereof.

55 Referring now to Figures 2 to 6, the metal fibers 14 have, as stated above, a rough outer surface 15 which is unmachined and unburnished. As is more fully explained below, the fibers may be produced by the tension breaking of longer filaments, with the result that the opposite ends 16 and 17 of a fiber are notched and the fiber has tapering end portions 18. As indicated in Figures 5 and 6, the mid-portion 19 of the fibers may

be curled or twisted in a plurality of directions with the different curls having mutually non-parallel axes. Intermediate the end portions 18, the fibers preferably have a substantially uniform cross-section. The fibers have a staple fiber length of at least approximately two inches, the staple fiber length being defined in the manner conventional in the textile art as the upper half mean of the array of all the fiber lengths.

70 It is within the scope of the invention to use fibers produced by cutting metal filaments to the desired staple lengths, in which case, the filaments may be supported by surrounding matrix material during the curving operation so that the ends of the cut fibers are straight.

75 Referring now to Figures 7 to 10, one preferred method of forming the fibers 14 comprises the steps of providing a plurality of metal rods 20 in a matrix 21 to define a billet 22. The billet is then reduced in diameter by a suitable constricting step, such as a wire drawing step as illustrated in Figure 7, to provide a reduced diameter composite 23. The composite 23 may be further reduced in diameter as by further drawing steps until the rods 20 define filaments 27 having an effective diameter (that is a mean transverse dimension) of under 50 microns. Illustratively, the rods 20 may be formed of stainless steel and the matrix 21 may be formed of monel metal with the effective diameter of the filaments 27 being approximately 12 microns in the final draw.

85 When the composite 23 has been reduced to the desired final diameter, the matrix material 21 is removed so as to leave the filaments 27 in the form of a tow 24. The removal of the matrix may be effected by any suitable means. Illustratively, where the filaments are stainless steel and the matrix material is monel metal, the matrix may be removed by leaching with a suitable acid such as nitric acid. As illustrated in Figure 9, the composite 23 may be arranged in the form of a spool to be submerged in the nitric acid 25 in a suitable tank 26.

90 As shown in Figure 10, the resultant tow 24 is comprised of a plurality of continuous filaments 27 in generally parallel arrangement. The filaments may be provided with zero twist as shown in Figure 10, or any suitable twist as desired, such as the conventional producer's twist of one-fifth of a turn per inch for facilitated handling of the tow 24. In forming the continuous filaments 27 by the above described drawing process, the filaments may have relatively long lengths such as over 50 feet. For use in the metal structure 10, the filaments are converted into suitable staple length fibers which may range from one-half to six inches, such as the two inch staple fibers discussed above.

130 One method of forming the staple fiber is to

break the filaments to form a continuous band of the broken fibers commonly called a sliver, such as sliver 28 illustrated in Figure 12. A method forming the sliver 28 from the tow 24 is illustrated in Figure 11 wherein the continuous filament tow 24 is fed through a breaking apparatus of a type used in the textile industry. This apparatus includes a plurality of in-feed rollers 29, a plurality of intermediate rollers 30, heater means 31 for heating the tow as it passes around the rollers 30, breaker bars 32, front rolls 33, and a crimper means 34. As shown in Figure 11, the tow 24 remains unbroken up to about breaker bars 32. The front rolls 33 are driven at a rate higher than the intermediate rolls to provide a draft, which may for example range from approximately 2-1/2 up to about 7-1/2. The respective filaments 27 of the tow 24 are thereby subjected to a tension. The breaker bars deflect the filaments from their normal straight line arrangement so that the different filaments break along different positions of the tow 24 whereby the continuity of the band is maintained while yet the individual filaments are broken to staple lengths to form the sliver 28. The sliver 28 as indicated above may be further formed as by crimping in apparatus 34 to form a crimped sliver 35 for facilitated subsequent handling.

The sliver is formed into the final porous metal structure by firstly opening and picking the sliver, as indicated in the several forming methods illustrated in Figures 13 to 15. It has been found that by making the metal fibers of sufficiently small size as discussed above (that is under 50 microns in diameter) that conventional textile apparatus 36 for opening and picking the sliver fibers may be employed to provide a bulk picked mass of fibers 37. The bulk fibers may then be fed behind a conventional textile card, or garnet, to form a sheet, or card web, 39. A plurality of the card webs 39 may then be laminated in a suitable textile laminating apparatus 40 to form a laminated metal fiber structure 41, the inter-engaging rough surfaces of the fibers being effective to inter-connect the different webs. To provide a more compacted mat, the laminated metal fiber structure 41 may be suitably annealed in conventional annealing apparatus 42 if desired and compacted in a conventional compacting apparatus 43 to provide the final laminated porous metal structure 10.

The density of the fibers in sheet 39 may be controlled by the rate of fiber input and by the selection of suitable card settings. In laminating the sheets 39, they may be cross-laid or parallel laid as desired. (While the carding operation effectively randomizes the fiber in the sheet 39, there is a slight machine direction to the orientation, that is there is a tendency for some preponderance of the fibers to extend in the direction of movement

through the card machine.) While the fibers in sheet 39 generally extend parallel to the plane of the sheet a small amount of curl, depending upon the cold work condition of the metal fibers in the picked bulk portion 37, is developed in the fibers as they are drafted over the card clothing. It has been found that such carding causes the individual metal fibers to be curled in a plurality of directions, the curls having mutually nonparallel axes as shown in Figures 5 and 6. The laminated fiber sheets 41 may be annealed as indicated above, if desired, to allow the fibers to take a new permanent set at a lower yield point and reduce their compressional resilience. For example, where the fibers are formed of 304 stainless steel, the annealing may be effected in an inert atmosphere at a temperature of roughly 1950° in apparatus 42. The compacting apparatus may comprise, for example, a platen press. By suitably controlling the compacting, an improved metal fiber structure 10 is provided having a high selected fiber density, selected sheet thickness and reduced pore size, high ratio of fiber surface area to volume of the structure 10, and controlled void percentage. The fibers effect a mechanical interlocking between themselves as a result of the curled arrangement thereof and their relatively rough surface characteristics. The fibers effectively comprise unburnished, unmachined fibers as formed by the above discussed multiple end drawing process.

In Figure 14, a modified method of practicing the invention in forming a porous metal structure 10' is shown to be generally similar to the method shown in Figure 13, except for the substitution of a creper apparatus 44 for the compacting apparatus 43. Illustratively, creper apparatus 44 may comprise a conventional paper micro-creper, such as the micro-creper manufactured by the Bird Machine Company of Walpole, Massachusetts, U.S.A. Such creper apparatus effectively crinkles the laminated web and effectively increases the multi-directional tensile, or burst, strength of the web. Further, the creped web 10' has a substantially increased extensibility, the amount of extensibility being controlled by the amount of areal reduction effected in the creper 44. As discussed above, the individual fibers of the laminated web 41 (and the annealed laminated web 41' where the annealing apparatus 42 is employed) extend generally parallel to the plane of the web so that the rough frictional characteristics of the fibers tends to hold them in the compacted state resulting from the creping operation providing the desired reduced area and thickness of the metal structure 10'.

If desired, the structure 10' may be returned into the creper 44 crosswise to the original direction of creping so that a further creping or compacting may be effected at right

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angles to the original creping. Illustratively, where the fibers are formed of 304 stainless steel, a total reduction in area of the web 41 of as much as 90% may be effected by such double right angle creping.

Turning now to Figure 15, a further modified method of forming a porous metal structure, such as porous metal structure 10, is shown to comprise a method generally similar to that of Figure 13, but wherein an air lay apparatus 45 is provided which by means of a turbulent air stream effectively randomizes the fiber arrangement in the output web. As indicated in Figure 15, the bulk fibers 37 may be delivered direct to the air lay apparatus 45, or (to improve the uniformity of distribution of the fibers in the output web) they may be passed through the card 38 and the resultant card web 39 delivered to the air lay apparatus 45, or the card webs 39 may be firstly laminated and then delivered to the air lay apparatus. The air lay apparatus 45 may be any conventional air lay apparatus well known to those in the textile art, one example thereof being shown in Figure 15 as the random-feeder-webber apparatus manufactured by the Curlator Corporation. Briefly, the apparatus includes a delivery conveyor 46 at the bottom of a hopper 47 in which the fibers 37, 39, or 41, as discussed above, are placed. An elevating conveyor apron 48 takes the fibers upwardly to a stripper conveyor apron 49 which forms tufts for delivery to an air bridge 50 conducting the fibers against a feed mat condenser screen 51. A suction fan 52 holds the fibers against the screen where they are compacted by a subjacent roller conveyor 53 and delivered past a feed roll 54 and a licker-in 55 to a condenser 56 against which the fibers are conducted by a cover 57 in the form of a web 41'' carried on a delivery conveyor 58 from the air lay apparatus 45. As in the previously indicated processes the web 41'' may be annealed by a suitable annealing apparatus 42 if desired before delivery thereof to the compacting apparatus 43 (or creper 44 as desired).

In certain instances, it is desirable to provide the fibers 14 of the porous metal structure 10 in different diameters. Thus, for example, as shown in Figure 16, a blend of different diameter fibers 14, 14', 14'', etc. may be provided by suitably delivering slivers 28 of different diameter staple fibers to the picking apparatus 36. In Figure 17, a different arrangement of the different diameter fibers is illustrated wherein different size fibers are provided in different layers of the laminated web 41''. When three or more layers are used, the fibers of successive layers may have progressively decreasing cross-sectional areas.

The individual fibers 14 extend randomly so as to engage each other in point contacts, as shown in Figure 18. The roughness and the

curled arrangement of the fibers 14, as indicated above, cause an effectively positive mechanical interlocking between the fibers in the resultant structure notwithstanding the limited contact between the individual fibers.

In addition to varying the arrangement of the porous metal structure by varying the diameters of the individual fibers thereof as discussed relative to Figures 16 and 17, different portions of the metal structure may have different average pore sizes thereof, such as in the structures 10E'' illustrated in Figure 19. Thus, different layers 11', 12' and 13' of fiber webs may be laminated, with the different layers having different average pore sizes, such as pore sizes 11'', 12'' and 13'' in the layers 11', 12' and 13', respectively. Thus, for example, the structure 10'' may be utilized as a filter structure wherein the pore size varies, e.g. decreases progressively in the direction of fluid flow therethrough.

In certain instances, it may be desirable to provide the metal structure in an uncompacted form. Illustratively, as shown in Figure 21, a metal structure 10''' embodying the invention is shown to comprise a random fiber web arrangement which, for example, may correspond to the web 41'' illustrated in the process of Figure 15.

The different porous metal structures discussed above may be utilized in many different applications such as in filter media including biological filter media of extremely small pore size, thermal insulation, vibration isolators, abrasives, reinforcement materials for reinforcing weak matricial materials such as elastomers, plastics, other metals, glass or ceramic materials, battery electrodes, fuel cell electrodes, display devices utilizing phosphorescent materials in the pores thereof, and laminates with other fibers and sheets of material.

In the illustrated embodiments of the invention, the metal fibers of the slivers 28 may be provided with relatively high degrees of cold working, and in the illustrated embodiment, may be at least approximately 85% cold worked. The forming of the porous metal structures from fibers of lesser effective diameter than the 12 micron effective diameter fibers mentioned above (for example fibers having effective diameters as small as 4 microns) both annealed and unannealed, has indicated that excellent porous metal structures may be produced in accordance herewith. The felt arrangement of the fibers in the porous metal structures provides an improved porous metal structure providing highly desirable advantages in many applications, such as those discussed above. The small size of the individual fibers permits the porous metal structure to constitute a flexible sheet which may be folded on itself without breakage of the individual fibers. The porous metal structure may constitute a drapable sheet,

that is a flexible sheet having sufficient "body" to retain the form given to it. Where extensibility is desired in the application, a creped sheet may be employed with control of the degree of creping providing a pre-selected desired resilient extensibility.

#### WHAT WE CLAIM IS:—

1. A porous metal web structure comprising a plurality of substantially fracture-free, unmachined and unburnished metal staple fibers each of which has in any selected cross-section a mean transverse dimension of less than 50 microns, said fibers having rough outer surfaces and being interlocked in an intermingled relationship substantially solely by means of said rough outer surfaces thereof in frictional engagement.
2. The metal structure of claim 1, wherein the individual fibers are curled in a plurality of directions, the curls having non-parallel axes.
3. The metal structure of claim 1 or 2, wherein the fibers constitute a carded web.
4. The metal structure of claim 1 or 2, wherein the fibers constitute a plurality of superposed interlocking carded webs.
5. The metal structure of any of the preceding claims wherein the individual fibers are at least approximately 85% cold worked.
6. The metal structure of any of the preceding claims, wherein the fibers have high compressional resilience.
7. The metal structure of any of claims 1 to 5, wherein the fibers comprise stress-relieved fibers.
8. The metal structure of any of the preceding claims, wherein the fibers have a mean transverse dimension of less than 12 microns.
9. The metal structure of any of the preceding claims, wherein the fibers are of substantially uniform cross-section throughout the central portion of their length.
10. The metal structure of any of the preceding claims, wherein all the fibers have substantially the same cross-sectional area.
11. The metal structure of any of claims 1 to 9 wherein the fibers are a blend of fibers having different cross-sectional areas.
12. The metal structure of any of claims 1 to 9, wherein the fibers are disposed in layers and the fibers of the respective layers have different cross-sectional areas.
13. The metal structure of claim 12, wherein the fibers are disposed in three or more layers and the fibers of successive layers have progressively smaller cross-sectional areas.
14. The metal structure of any of the

preceding claims, wherein the fibers are disposed in layers and the respective layers have different average pore sizes.

15. The metal structure of any of the preceding claims, wherein the fibers have a staple fiber length of at least two inches.

16. The metal structure of any of the preceding claims, wherein the fibers are compacted.

17. The metal structure of any of the preceding claims, wherein the metal structure is creped.

18. The metal structure of any of the preceding claims, wherein the structure is a flexible sheet.

19. The metal structure of any of claims 1 to 17, wherein the structure is a flexible sheet capable of being folded on itself without breakage of said fibers.

20. The metal structure of any of claims 1 to 17, wherein the structure comprises a flexible sheet which will maintain the form given to it.

21. The metal structure of any of the preceding claims, wherein the fibers have notched ends.

22. The metal structure of any of the preceding claims, wherein the fibers have the form obtained by the tension breaking of filaments, the fibers having tapering end portions.

23. A porous metal web structure having substantially the constitution of any one of the embodiments of the invention herein described with reference to the accompanying drawings.

24. A staple metal fiber having a fracture free unmachined and unburnished outer surface, said fiber having an effective diameter of less than 50 microns and a substantially uniform cross-section.

25. The staple metal fiber of claim 24, wherein the fiber has cut ends.

26. The staple metal fiber of claim 24, wherein the fiber has tensilely broken ends.

27. The staple metal fiber of claim 26, wherein said ends of the fiber are tapered.

28. The staple metal fiber of claim 26, wherein said ends of the fiber are substantially frustoconical.

29. The staple metal fiber of claim 25, wherein said cut ends of the fiber are formed by cutting the fiber while the fiber is completely supported in a surrounding matrix.

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